EIC Background Studies Impact on the IR and Detector Design

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Introduction

- **EIC High Luminosity** performance is mandatory in order to start the nucleon nuclear structure measurements on Day 1

- EIC IR and Detector concepts are designed to best enable the physics of the EIC whitepaper and made in close collaboration with the accelerator design

This requires thorough quantitative background studies to ensure the high luminosity and full acceptance reach

Goals of the Proposal

Study background generated by machine operation in simulation:

- **Synchrotron radiation**
- **Beam-gas interactions**

Focus of this proposal

- Beam halo effects and beam losses
- Neutron flux
- Others

➤ **Quantify background rates and radiation doses in order to assess the impact on**

- **Detectors' operation, electronics, beamline components, etc.**

➤ **Provide input**

- **Machine lattice, IR design: beam pipe, magnets, vacuum/pumping**
- **Detector design, technology choices & Support structures, etc.**

It is critical to perform a thorough study of the type/dose and distribution of machine induced background **NOW** that the IR is being designed

Main Background Sources

- **Electron beam**

  - **Synchrotron radiation**
    - Backscattering
    - Photo desorption
      -> degradation of vacuum

  - **Beam gas interactions**
    - Off momentum electrons

  - **Higher order mode losses**
    - Local heating at injection
    - and ramp (short bunches)
   - -> degradation of vacuum

- **Proton\Ion beams**

  - **Beam gas interaction, large hadronic cross section**
    - Background in detector
    - Secondary interactions with aperture limitations, i.e. with magnets, beam pipe, masks

Need:
- **Careful design of the IR**
- **Beam wakefields**
- **SR masks**
- **Excellent vacuum system**

Tools and Methods

- **GEANT4/GEMC**
  - Detector and beam pipe modeling

- **Beam distribution/emittance**
  - Input to GEANT4

- **Synchrotron Radiation tools developed at SLAC (SR code)**
  - Input to GEANT4

- **Molflow+**

- **Synrad**

Vacuum Modeling Installed at JLab → Input → GEANT4
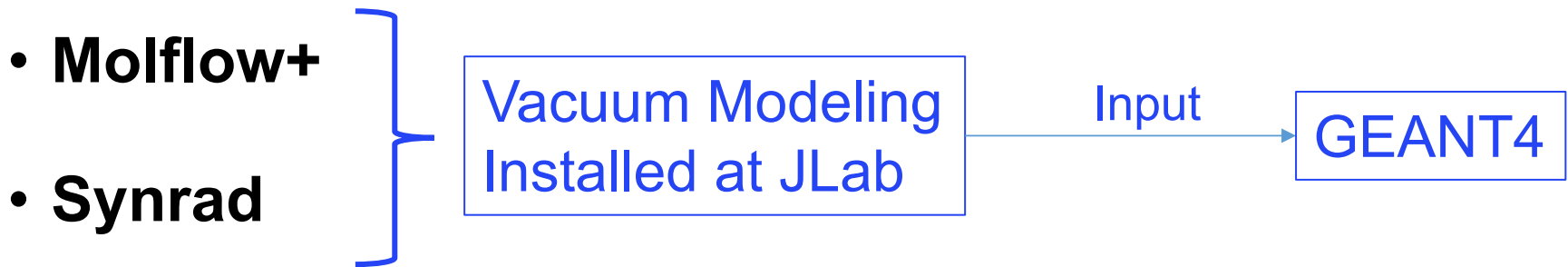
SR- Photon Generation (SR-Code)

- A gaussian transverse electron beam profile with wide gaussian tails

- Each electron is traced through the given magnetic elements and a photon critical energy is calculated based on the trajectory curvature

- The SR fan start and stop points of each magnetic element are also found and traced through a series of beam pipe apertures where the fraction of the fan hitting each aperture is recorded

- A generator of scattered photons is built from of SR photons found in the energy ranges for a give aperture: the result is the number of scattered photons from the mask tip for example

- **Each photon (energy, position and direction) are then saved to a file that can be read in by a GEANT**
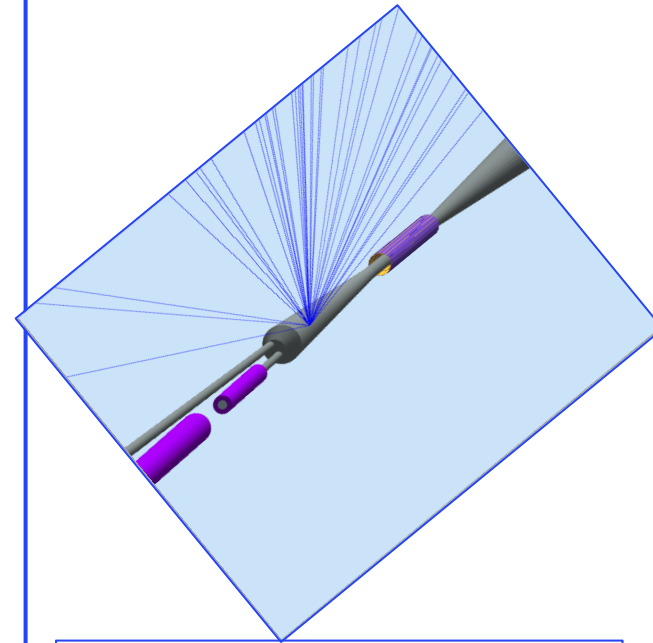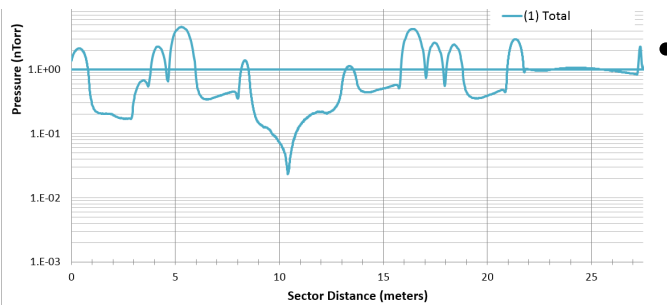

Number of incident photons on this mask tip per beam bunch: 6.9e7.

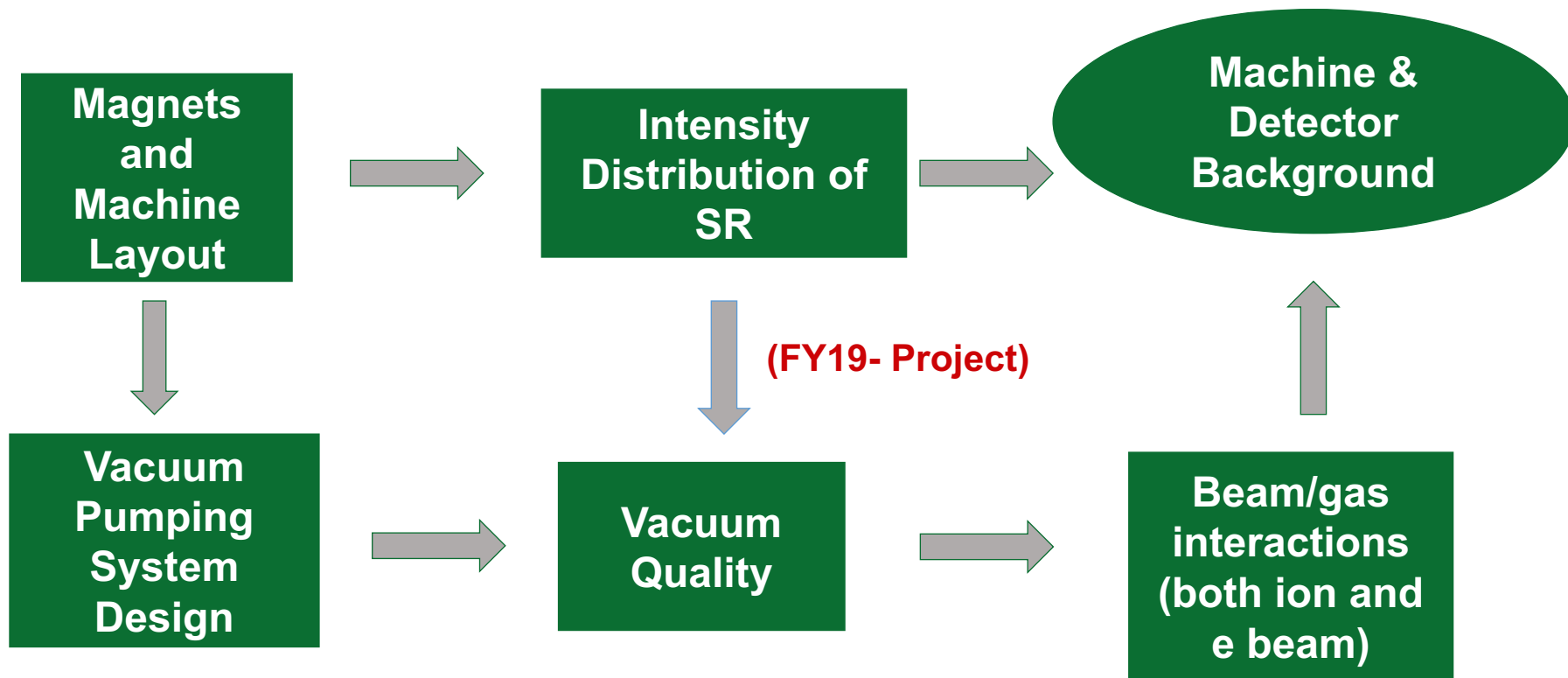The actual number of scattered photons per beam bunch : 9751

Vacuum Modeling Tools
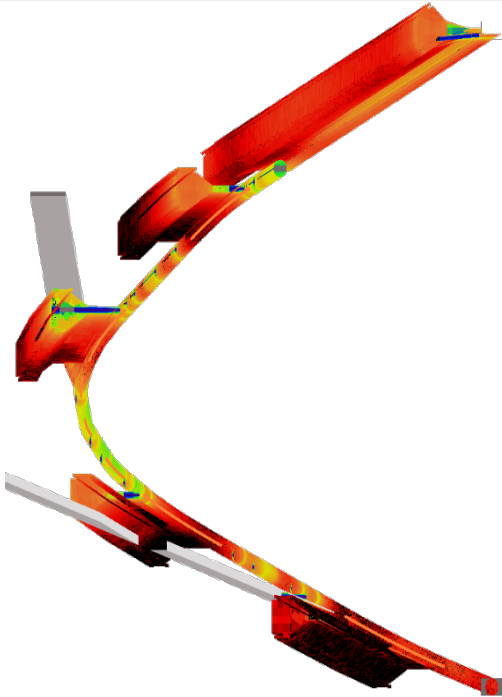
- Molflow+ and Synrad modeling software developed by Roberto Kersevan & Marton Ady

  - **Molflow+**: static vacuum modeling
  - **SynRad:** model of vacuum events due to beam

- Jason Carter, ANL, used Molflow+/Synrad to model static and dynamic vacuum for APS upgrade

- Jason Carter, ANL, and Marton Ady, CERN, used Molflow+/Synrad for SuperKEKB interaction region

- CAD designs of beamline are combined with pumping speeds and outgassing rates of elements yield expected pressure becomes input to our GEANT simulations.

Background Studies Workflow

```
Magnets and Machine Layout  →  Intensity Distribution of SR  →  Machine & Detector Background
        ↓                              ↓ (FY19- Project)                    ↑
Vacuum Pumping System Design  →  Vacuum Quality  →  Beam/gas interactions (both ion and e beam)
```

Lessons from HERA II Upgrade

- **Severe background problems in the year 2002 significantly delayed startup of HERA after luminosity upgrade**
  - **No careful simulations prior to the upgrade**
- **Most of the background came from proton-beam gas interactions where vacuum deteriorated due to synchrotron radiation.**
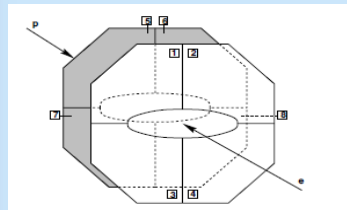
Al (100%)

10^{-10} mbar 10^{-8} mbar 10^{-10} mbar

We used HERA II data to benchmark our tools and procedures
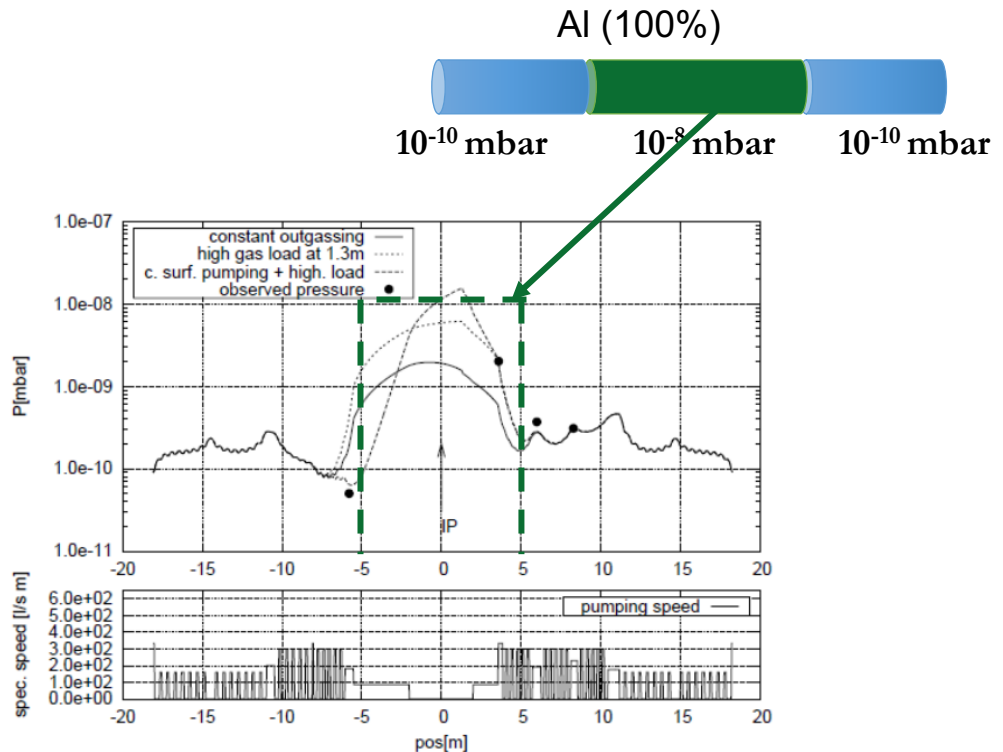
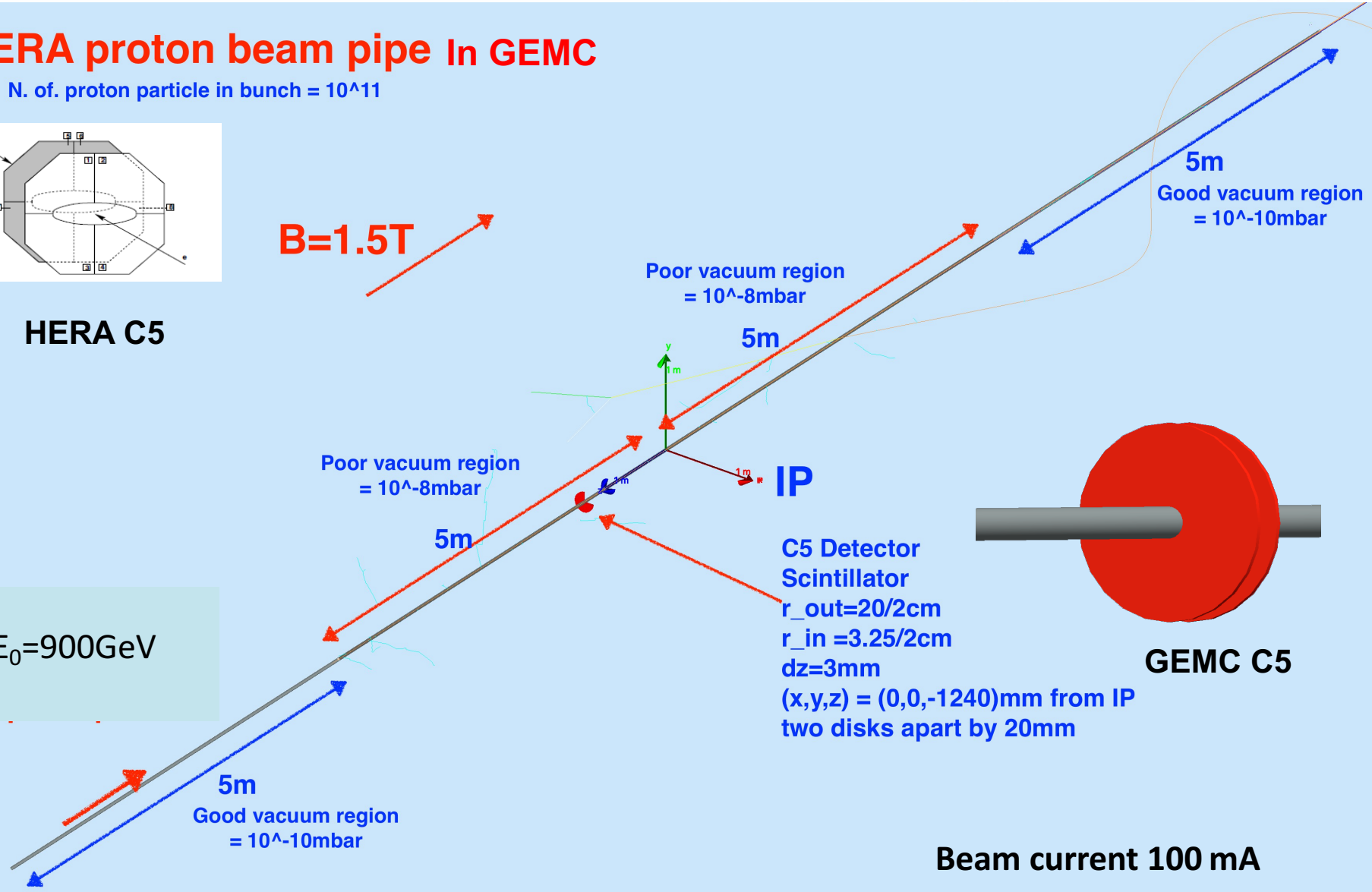# HERA Configuration Simulated in our Framework

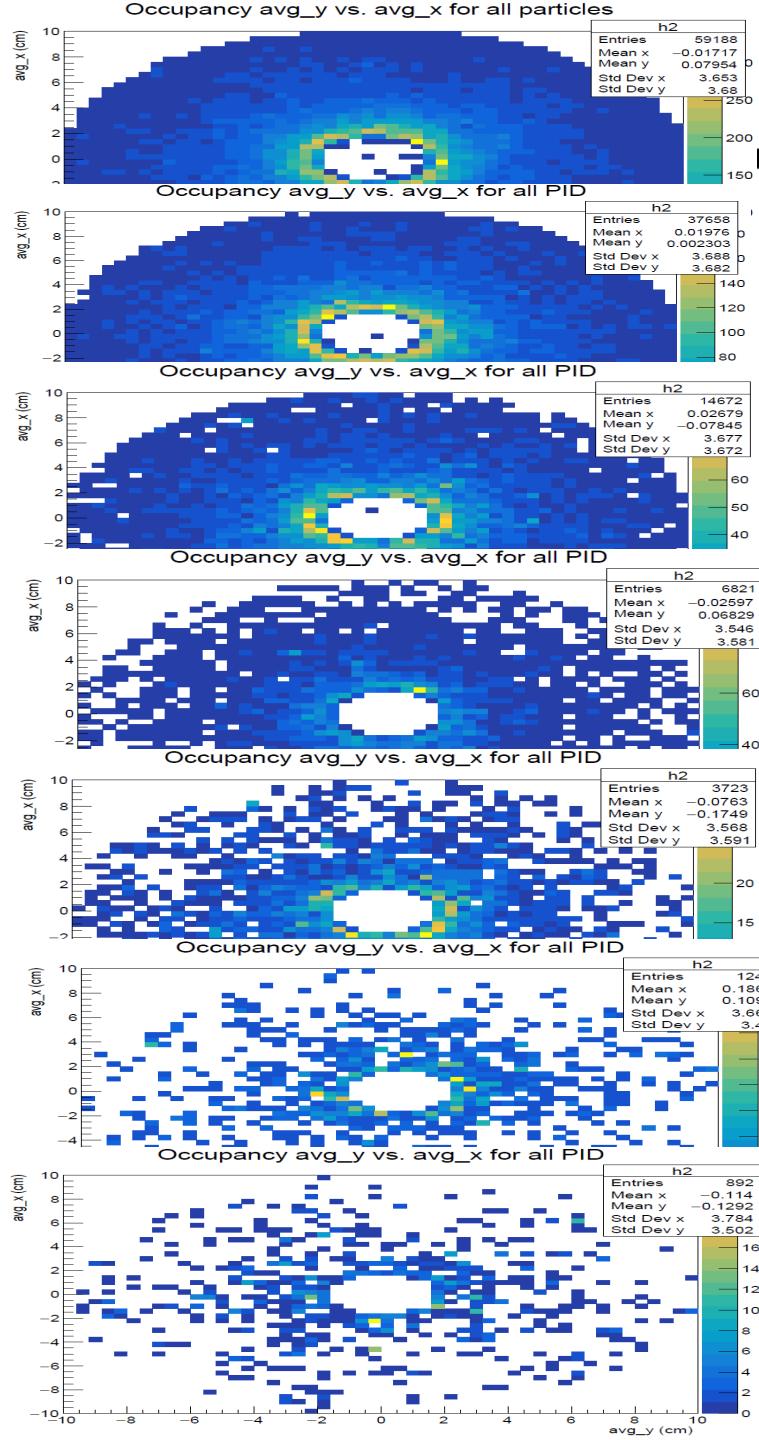**HERA proton beam pipe** In GEMC

N. of. proton particle in bunch = 10^11

HERA C5

B=1.5T

Good vacuum region = 10^-10mbar

Poor vacuum region = 10^-8mbar

5m

Poor vacuum region = 10^-8mbar

5m

IP

E_0=900GeV

C5 Detector Scintillator
r_out=20/2cm
r_in =3.25/2cm
dz=3mm
(x,y,z) = (0,0,-1240)mm from IP
two disks apart by 20mm

GEMC C5

5m
Good vacuum region = 10^-10mbar

Beam current 100 mA

10⁻⁸mbar: 10^{-8}mbar — BG rate ~ 66kHz (**33kHz** from Charge particles)

0.5*10⁻⁸mbar: $0.5*10^{-8}$mbar — BG rate ~ 31kHz

0.2*10⁻⁸mbar: $0.2*10^{-8}$mbar — BG rate ~ 13kHz

0.1*10⁻⁸mbar: $0.1*10^{-8}$mbar — BG rate ~ 7kHz

0.05*10⁻⁸mbar: $0.05*10^{-8}$mbar — BG rate ~ 3kHz

0.02*10⁻⁸mbar: $0.02*10^{-8}$mbar — BG rate ~1.3kHz

0.01*10⁻⁸mbar: $0.01*10^{-8}$mbar — BG rate ~0.4kHz

10^{-8}mbar

Results of our simulation of HERA

10^{-10}mbar

Jefferson Lab

Good agreement of our simulation rate to the measured rate at HERA!
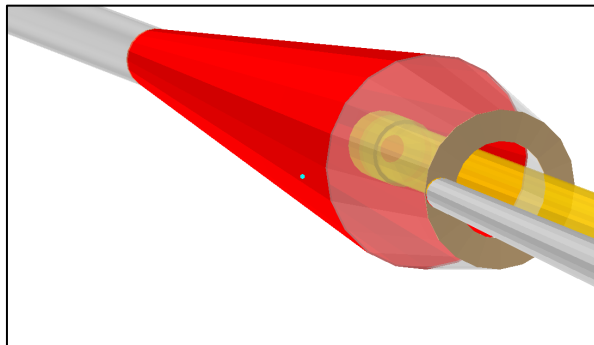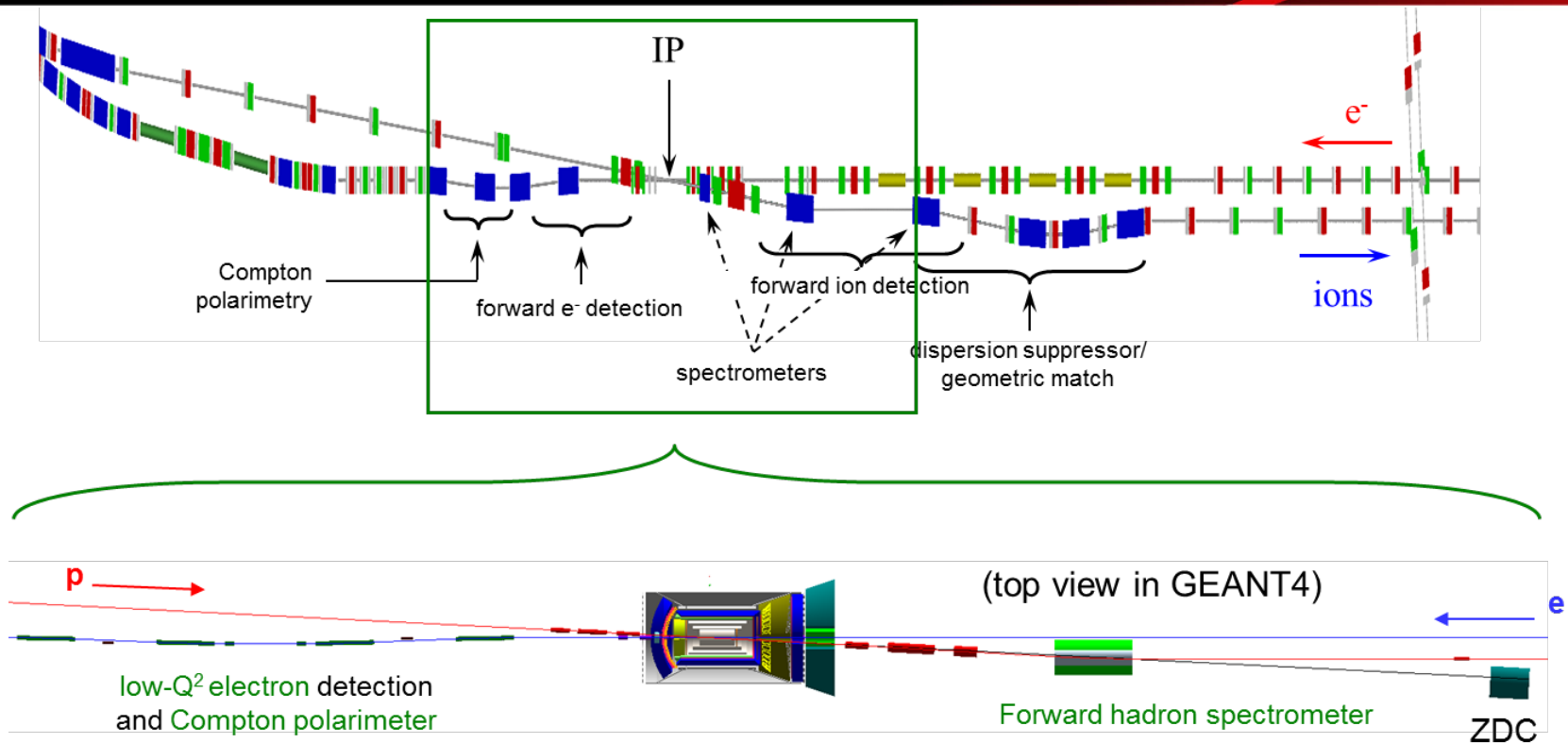
From our simulation of HERA

- The rate of the particles in the simulated C5 detector was calculated for HERA parameters and measured **33 kHz** for charged particles in agreement with ZEUS data

- For more systematics, additional studies were made, varying the vacuum region length, physics model and beam pipe material composition, whish showed the expected dependence on each parameter
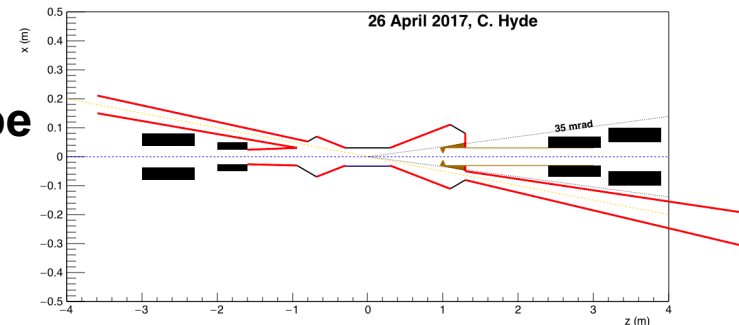
From measurement at HERA

C5 rate as a function of HERA e beam current for different p beam current
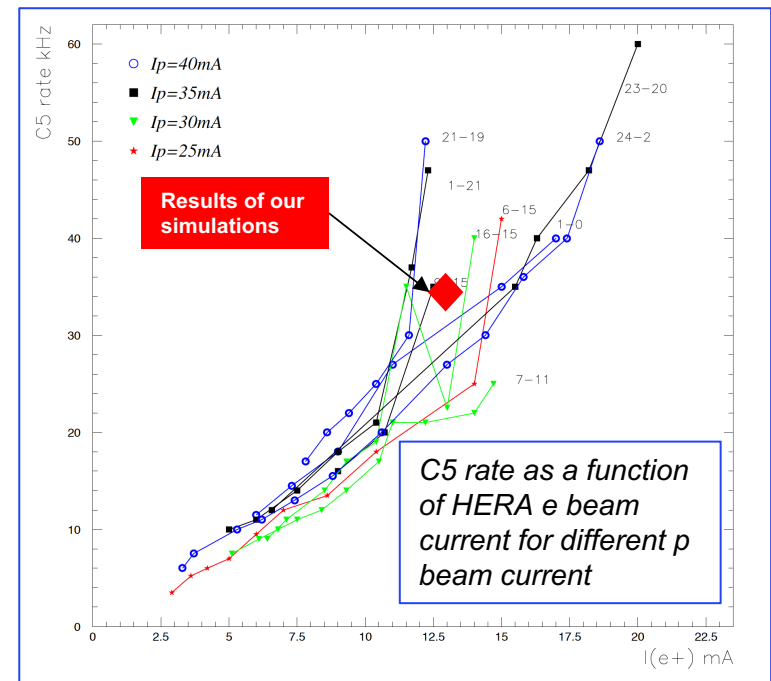
Validation and benchmarking of our simulation tools and procedures

JLEIC Interaction Region

IP

Compton polarimetry

forward e⁻ detection

forward ion detection

spectrometers

dispersion suppressor/ geometric match

e⁻

ions

p

(top view in GEANT4)

e

low-Q² electron detection and Compton polarimeter

Forward hadron spectrometer

ZDC

Beam Pipe

26 April 2017, C. Hyde

35 mrad

Deliverables Full Funding

FY18: First and second quarters

- Model the current baseline design of JLEIC IR beam pipe concept in GEMC/GEANT4 simulations.

- Benchmark synchrotron radiation rates produced within GEANT4 and compare with SR code simulations.

- Develop an interface of the SR code to GEMC

- Model the current baseline design of JLEIC IR beam pipe concept in a 3D CAD model.

FY18: Third and fourth quarters:

- Determine background rates as a function of vacuum levels for the JLEIC configuration

- Determine the intensity and distribution in the beam pipe and in the various detectors using GEMC interfaced with SR code

- Using validated software tools and result of beam pipe design, evaluate background contributions from hadron beam/gas interactions under nominal vacuum levels.

- Interface CAD drawings with Molflow+ and Synrad+ in preparation of FY19 project

Deliverables at 80% Funding Level

FY18: First and second quarters

- Model the current baseline design of JLEIC IR beam pipe concept in GEMC/GEANT4 simulations.

- Benchmark synchrotron radiation rates produced within GEANT4 and compare with SR code simulations.

- Develop an interface of the SR code to GEMC

- Model the current baseline design of JLEIC IR beam pipe concept in a 3D CAD model.

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- Using validated software tools and result of beam pipe design, evaluate background contributions from hadron beam/gas interactions under nominal vacuum levels.

- Interface CAD drawings with Molflow+ and Synrad+ in preparation of FY19 project

Deliverables at 60% Funding Level

FY18: First and second quarters

- Model the current baseline design of JLEIC IR beam pipe concept in GEMC/GEANT4 simulations.

- Benchmark synchrotron radiation rates produced within GEANT4 and compare with SR code simulations.

- Develop an interface of the SR code to GEMC

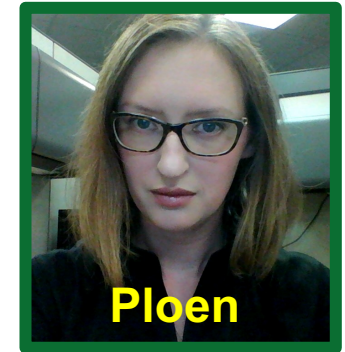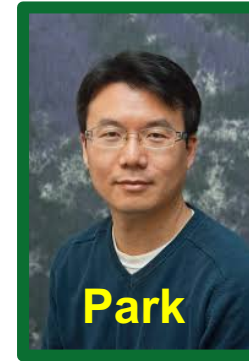- Model the current baseline design of JLEIC IR beam pipe concept in a 3D CAD model.

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- Determine background rates as a function of vacuum levels for the JLEIC configuration

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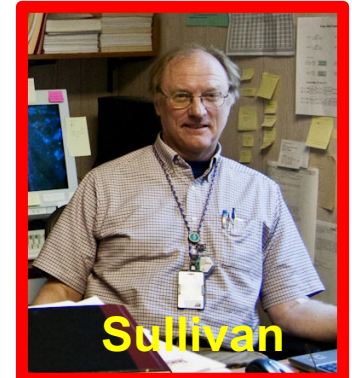
R&D Personnel (FY18)

Background Simulation studies

Elouadrhiri Park Ploen

Machine/IR design & SR modeling

Hyde Morozov Sullivan

Detector design

CAD modeling & Vacuum calculation

Furletova Michalski Stutzman

Jefferson Lab

Funding Request

Resources	FY18		
	100% Funding	80% Funding	60% Funding
Post-Doc (JLab)	$25k	$11k	$0k
Student (ODU)	$35k	$35k	$35k
Travel (Consult M.S. from SLAC) JLab Responsibility	$10k	$10k	$7k
Total	**$70k**	**$56k**	**$42k**

Institutions	100% Funding	80% Funding	60% Funding
JLab	$35k	$22k	$7k
ODU	$35k	$35k	$35k

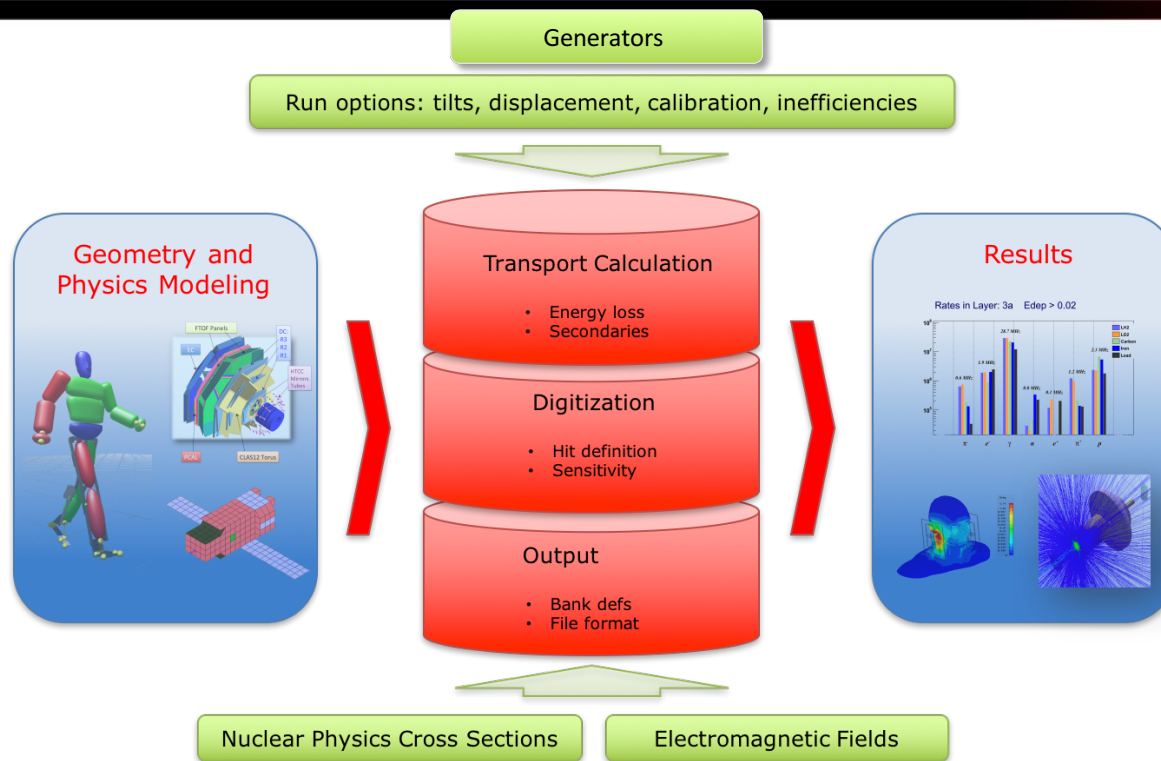***Note:*** *The costs are fully burdened*

Summary

We request funding to perform detailed simulations of the EIC machine related background

- Create validated and benchmarked simulations tools and procedures:

    - GEANT simulation: complete the HERA benchmarking
    - Synchrotron radiation modeling code
    - Static vacuum modeling
    - Vacuum events due to beam (FY19 Project)

- Apply these procedures to the JLEIC configuration and provide input to optimize the IR design

Knowledge gained from this proposal is critical to the machine and detector design for both JLEIC and eRHIC

GEant4 MonteCarlo (GEMC)

Generators

Run options: tilts, displacement, calibration, inefficiencies

Geometry and Physics Modeling

Transport Calculation
- Energy loss
- Secondaries

Digitization
- Hit definition
- Sensitivity

Output
- Bank defs
- File format

Results

Rates in Layer: 3a Edep > 0.02

GEMC makes available all the powerful geant4 features w/o need of c++ or geant4 knowledge. It provides:

- **application independent geometry description**

- **easy interface to build / run experiments**

- **cad/gdml imports**

Nuclear Physics Cross Sections

Electromagnetic Fields

CLAS12

JLEIC

HPS

SOLID
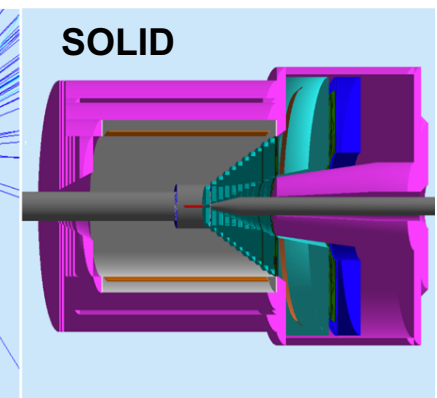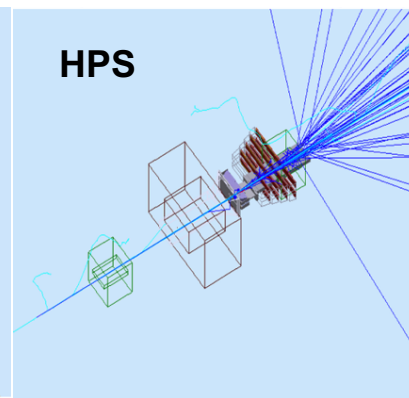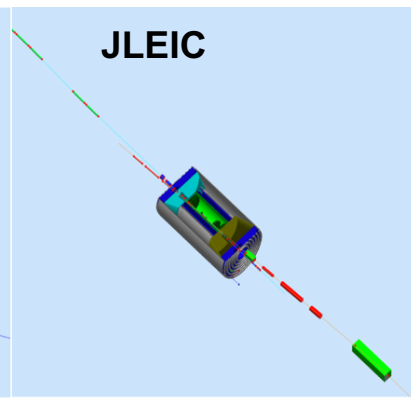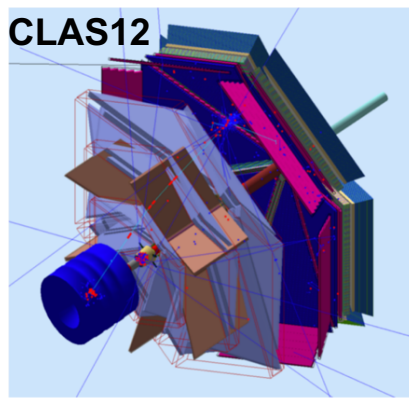
Physics Processes Included in GEMC

Process	ID	Process	ID	Process	ID
E Ionization	1	h Ionization	22	Mu Brems	62
Compton	2	H Pair Prod	23	Muon Nuclear	63
E Brems	3	Proton Inelastic	30	Kaon – Inelastic	70
Phot	4	Neutron Inelastic	31	Kaon + Inelastic	71
Conversion	5	N Capture	32	Kaon 0 Inelastic	72
Annihilation	6	Anti neutron Inelastic	33	Kaon 0L Inelastic	73
Photon Nuclear	7	SynRad	35	Kaon OS Inelastic	74
E- Nuclear	8	Pi-Inelastic	40	alpha Inelastic	80
E+ Nuclear	9	Pi+ Inelastic	41	lambda Inelastic	90
Coulomb Scatter	10	Decay	50	sigma Inelastic	100
Cerenkov	11	Decay With Spin	51	d Inelastic	110
Hadronic Elastic	20	Mu Ionization	60	ion Ionization	120
hBrems	21	Mu Pair Prod.	61	t Inelastic	130